METHOD AND DEVICE FOR THE REFLECTION OF CHARGED PARTICLES ON SURFACES

BACKGROUND OF THE INVENTION

The storage or guidance of ions in volumes of any form defined by real or virtual walls requires reflection of the ions at or near the walls without the ions being discharged. For example, mechanical enclosure is ineffective because the ions are discharged at the physical walls. Up until now, ion-conserving reflections have been limited to two-dimensional and three-dimensional radio frequency (RF) multipole fields. These are more general forms (with more poles) of the two-dimensional and three-dimensional RF quadrupole fields invented by Wolfgang Paul and Helmut Steinwedel. Multipole rod systems have been used for several years for the guidance of ions in bad or moderate vacuums where collisions with a residual gas damp the movement of the ions.

In multipole rod systems, two-dimensional multipole fields are spanned between at least two pairs of rods, arranged evenly on the surface of a cylinder parallel to its axis. The two phases of an RF voltage are fed to the rods, opposite polarities existing between neighboring rods. Two pairs of rods span a quadrupole field, increasing numbers of rod pairs span hexapole, octopole, decapole, and dodecapole fields. The fields are called two-dimensional because any cross-section perpendicular to the axis exhibits the same field distribution; there is no dependence of the field distribution on the relative location along the axis of the device.

Three-dimensional multipole fields form the class of RF multipole ion traps. They consist of at least one ring electrode (the number of ring electrodes depending on the type of trap) and exactly two end cap electrodes. One ring electrode and the obligatory end cap electrodes span a quadrupole ion trap, two rings plus end caps form a hexapole, three rings produce an octopole, and four rings a decapole ion trap.

Radio frequency multipole rod systems are frequently used either as mass filters for inexpensive mass spectrometers, or as ion guides for transporting ions between ion production and ion consumption devices, particularly in feeding mass spectrometers of any type. Radio frequency multipole rod systems are favorably suited as ion guides for ion trap mass spectrometers, such as RF quadrupole ion traps or ion cyclotron resonance (ICR) mass spectrometers. Ion trap mass spectrometers operate cyclically with ion filling phases and ion investigation phases, and ions must not be introduced during the investigation phases. Ions can be temporarily stored in such ion guides by reflecting end potentials (as described in U.S. Pat. No. 5,179,278). Temporary storage of ions produced during the ion investigation phase therefore allows an increase in the duty cycle of the ion source. Furthermore, such ion guides can be used to thermalize ions produced outside the vacuum system of a mass spectrometer, and accelerated by the process of introducing them into the vacuum system. Thermalization requires a collision gas, and the residual gas inside a differential pumping stage can easily be utilized as such (see, e.g., U.S. Pat. No. 4,963,736).

Multipole rod systems for the guidance of ions usually have small diameters to concentrate the ions in a narrow area around the axis. The narrow area forms a pointed virtual ion source for excellent optical focusing of the ions exiting the ion guide. The inner, open diameters of these rod systems

amount frequently to 3 to 6 millimeters only, the rods are usually less than 1 millimeter in diameter, and the system is about 5 to 15 centimeters long. The rods are mounted to notches in ceramic rings. There are high requirements to the precision of the arrangement. The system is hard to produce and sensitive to vibrations and shock. The rods get bent very easily, and cannot be re-adjusted with the required precision.

It is the objective of this invention to create methods and devices for the reflection of charged particles at or above surfaces. It is further the object of the invention to enclose charged particles in arbitrarily formed volumes with or without openings, and to transport ions without losses. The invention should be suited to form narrow, long ion guides with a mechanically robust structure, having good aptitude for thermalization and temporary storage of ions. It should be possible to produce inexpensive mass filters by this invention.

SUMMARY OF THE INVENTION

It is the basic idea of the invention to create strong but inhomogeneous RF fields of short space penetration for the reflection of charged particles of both polarities at arbitrarily formed surfaces.

An RF field around the tip of a wire drops in field strength proportional to $1/r^2$, the RF field of a long, thin wire drops with $1/r$, where r is the distance to the wire tip, or to the wire axis. Both fields reflect positively or negatively charged particles. The particle oscillates in the RF field. Independent of its polarity, it encounters its largest repelling force exactly when it is located in its position nearest to the wire, which is the point of strongest field strength during the oscillation. It encounters its strongest attracting force exactly in its location farthest from the wire, i.e., in the point of lowest field strength during its oscillation. Integrated over time, a repelling force results. This integrated repelling force field often is called "pseudo force field", described by a "pseudo potential distribution". The pseudo potential is proportional to the square of the RF field strength; it drops with $1/r^4$ in case of the tip, and with $1/r^2$ in case of the long wire, but is, in addition, inversely proportional to both the particle mass m and the square ω^2 of the RF frequency ω.

If there are two nearly adjacent wire tips connected to the two phases of an RF voltage, both tips repel ions of any polarity. Their total effect is stronger than that of a single tip. It is well-known that the field strength of the dipole drops more quickly than $1/r^2$. In the present invention, a two-dimensional array of wire tips is provided, with neighboring tips alternately connected to different RF phases. The array of wire tips forms a surface which repels (or reflects) particles of both polarities at short distances. In a distance which is large compared to the distance between neighboring wire tips, the RF field is negligible. Reflection in this case belongs to the class of diffuse reflections, in contrast to specular (or regular) reflection.

In addition to the grid of wire tips, the present invention includes other reflective surface embodiments. In one embodiment, long parallel wires are spaced closely together. The wires are attached to two opposite phases of an alternating voltage such that every other wire has the same phase and, for each wire, the two wires adjacent to it have the opposite phase to it.

In another embodiment, a reflective surface is formed from a combination of wire tips and a wire mesh arranged around the tips. A particular form of this embodiment has the wire mesh shaped like a "honeycomb" structure, with a wire tip located in the center of each "cell" of the honeycomb.